

# Did GRB 970228 and GRB 970508 present similar optical properties?

C. Bartolini<sup>1</sup>, G.M. Beskin<sup>2</sup>, A. Guarnieri<sup>1</sup>,  
N. Masetti<sup>1</sup> & A. Piccioni<sup>1</sup>

<sup>1</sup>*Dipartimento di Astronomia, Università di Bologna, Italy*

<sup>2</sup>*Special Astrophysical Observatory of RAS, Nizhnij Arkhyz, Russia*

**Abstract.** The analysis of the light curves of the optical counterparts of GRB 970228 and GRB 970508 points out remarkable similarities. The spectral distribution obtained from the color indices shows that both the transients became bluer during the increasing stage, and redder after the maximum. A main difference concerns the behaviour of the optical fading which is well fitted by a single power law in the case of GRB 970508 but not in the case of GRB 970228.

## GRB 970228

The optical counterpart of GRB 970228 was discovered by van Paradijs et al. [18] who observed it for the first time on February 28.99 UT, 1997. Early observations by Guarnieri et al. [11] in the  $B$  and  $R$  bands on February 28.83 allowed the detection of the presence of a rising branch in the light curve.

Fig.1 (left) shows the  $R$  light curve obtained by using the collection of observations reported by Galama et al. [8] and the data by Guarnieri et al. [11] and Fruchter et al. [6]. Pedichini et al.'s [15] observations were not included because of the difficulty to reduce their color system to the  $R$  band. A fitting of the optical data with a single power law yields an index  $\alpha_{\text{opt}} = 1.21 \pm 0.02$ ; however, data reported by Galama et al. [8] show a decay behaviour which seems to follow a power law with spectral index  $\alpha_{\text{opt}} = 2.1$  before March 6, 1997, and with  $\alpha_{\text{opt}} < 0.35$  after that day.

The evolution of the optical spectrum of GRB 970228 is presented in Fig. 1 (right). The flux densities were evaluated from the photometric data taken on February 28.83 [11], February 28.99 [18], March 26.4 and April 7.2 [17] using the formulae by Fukugita et al. [7]. The optical transient became bluer during the rise and then, on its way to quiescence, significantly reddened, going from  $B - V = 0.5$  and  $V - R = 0.5$  on February 28.83 to  $V - R = 0.4$  and  $V - I = 0.7$  on February 28.99, to  $V - R = 0.9$  and  $V - I = 1.9$  on March 26.4.

**FIGURE 1. Left:**  $R$  light curve of the optical transient associated with GRB 970228. Data were taken from literature (see text),  $t$  is the time interval, in days, since the  $\gamma$ -burst. **Right:** broadband spectra of GRB 970228; the flux densities were computed from the photometric data by Guarnieri et al. [11] (triangles), van Paradijs et al. [18] (squares) and Sahu et al. [17] (circles). The HST data were multiplied by a factor of 10 for sake of clarity. The data corresponding to the open symbols are evaluated from the measured values (filled symbols) using a linear interpolation of the flux densities.

## GRB 970508

Surprisingly — but not too much in the light of the behaviour found by Guarnieri et al. [11] for GRB 970228 — the optical transient discovered by Bond [1] inside the GRB 970508 error box increased in brightness during the first two days after the  $\gamma$ -burst, reaching the peak around May 10.8 UT. According to Castro-Tirado et al. [2] during this phase the object was very blue.

Its  $R$  light curve is shown in Fig. 2 (left). The data were taken from the IAU Circulars, from several papers published in these proceedings and from Kelemen [12]. An upper limit to the brightness was obtained with the Bologna Telescope on May 23.89 UT. A power-law decay fits the data until 50–60 days after the  $\gamma$ -burst. We obtain  $\alpha_{\text{opt}} = 1.34 \pm 0.02$ , which is slightly higher than the values found by Djorgovski et al. [3], Kopylov [13] and Fruchter et al. [5]. Then, the light curve seems to flatten about at  $R \approx 25.2$ , which might be the magnitude of the host galaxy [16].

The observations by Galama et al. [9], Groot et al. [10], Kopylov et al. [14] and Kopylov [13] are homogeneous and cover almost all the optical band in the same time lapse. From these data, we evaluated the flux densities and

**FIGURE 2. Left:**  $R$  light curve of the optical transient associated with GRB 970508. Data and upper limits are from various authors (see text for details).  $t$  represents the time interval, in days, since the  $\gamma$ -burst occurred. **Right:** broadband spectra of GRB 970508 built with the flux densities computed from the photometric data by Galama et al. [9] on May 10.05 (triangles) and on 11.03 (squares), and by Groot et al. [10] on 12.03 (circles).

the broadband spectral evolution of GRB 970508 using the same procedure applied to GRB 970228 data; the results are reported in Figs. 2 (right) and 3 (left). On May 10.05 the object was red; then, it became progressively bluer on May 10.77, 10.93, until it reached a maximum on May 11.03, close to the light peak. On May 11.76, the spectrum became flatter (Fig. 3, left) but on May 12.03, the slope rose again at short wavelengths (Fig. 2, right). Subsequently the spectrum started to redden, peaking in the  $R$  on May 22.00. This behaviour is confirmed by the trend of the color of the optical transient (Fig. 3, right).

It is noteworthy that the  $B - V$  secondary maximum occurred around the appearance of a transient radio emission associated to GRB 970508. Indeed, nearly a week after the onset of the  $\gamma$ -burst, Frail et al. [4] found a flaring radio source, increasing in brightness, which was coincident with the positions of the X-ray and optical counterparts of GRB 970508.

## COMPARISON BETWEEN THE LIGHT CURVES

Although the light curve of GRB 970228 is less sampled, we can see remarkable similarities with that of GRB 970508, by comparing the left panels of Figs. 1 and 2. Both light curves show a rising branch. In particular, the

**FIGURE 3. Left:** broadband spectra of GRB 970508 built with the flux densities computed from the photometric data by Kopylov et al. [14] and Kopylov [13]. The upper limit in the figure refers to May 22.00. **Right:**  $B - V$  colors of GRB 970508 from May 10 to May 14. Dutch data are indicated with open squares, and Russian ones with filled squares.

maximum occurred  $\sim 1$  day after the burst for GRB 970228, and around 2 days after for GRB 970508. Therefore, the presence of a delayed maximum in the optical light curve appears to be a common feature for all the GRBs observed thus far.

The two light curves show similar overall decays. But if the  $R$  light curve of GRB 970508 can be fitted with a single power law until 60 days from the onset of the  $\gamma$ -burst, the one of GRB 970228 does not; indeed, Guarnieri et al. [11] noticed a more rapid decrease during the first 3 days after the  $\gamma$  event.

## COMPARISON BETWEEN THE SPECTRA

The spectral distribution (Figs. 1 and 2, right, and Fig. 3, left) and the  $B - V$  color index (Fig. 3, right), show that both the optical transients became bluer during the rising phase, and then reddened during their approach to quiescence. This could be simply understood in the light of the ‘fireball’ model (e.g. Wijers et al. [19]): a moving shock wave heats the surrounding medium, which then cools down. In this framework, the fast spectral and color variation of GRB 970508 in the optical is therefore surprising.

Due to the paucity of the observations, we cannot say if GRB 970228 showed a similar behaviour during the first days after the burst. However, if these variations are connected with the radio transient and since no radio emission

was revealed for GRB 970228, it is possible that no such changes in the optical spectral energy distribution took place in GRB 970228.

Another explanation for these spectral changes could arise from the presence of cool absorbing material placed on the line-of-sight at a distance of about 2 or 3 light-days from the center of the burst; it could have produced a ‘dip’ at shorter wavelengths suddenly after the light peak, and then could have been shocked by the blast wave in the following days.

It seems that GRB 970228 was redder than GRB 970508 at light peak ( $B - V = +0.5$  instead of  $+0.1$ ). However we are not sure that the minimum  $B - V$  for GRB 970228 has been observed. Moreover, this value could be affected by interstellar (and/or intergalactic) absorption; indeed, GRB 970228 lies closer to the galactic plane than GRB 970508. Actually, the absorption in the  $V$  towards GRB 970228 is  $A_V = 0.4$  mag [18], while towards GRB 970508 is only  $A_V = 0.08$  mag (derived from the  $A_B$  value reported by Djorgovski et al. [3]).

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